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Theoretical and Experimental Investigations of Antennas and Waves in Plasma

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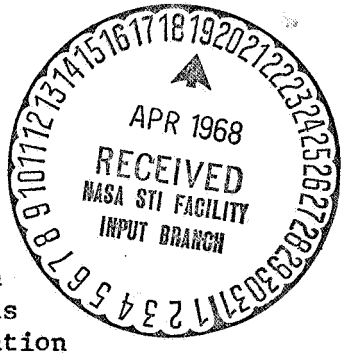

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Diffraction of Electromagnetic Waves by Moving Striations in a Plasma Column - Experimental and Theoretical Studies - B. Rama Rao and W.A. Saxton.

Moving striations are periodic, macroscopic waves of ionization moving within the positive column of the glow discharge of an inert gas. Experimental and theoretical investigations have been made to study the diffraction of microwaves by large amplitude, regular striations inside a plasma column. The phenomenon observed here is similar to the Bragg scattering of light by means of elastic waves in liquids and solids. The spectrum of the diffracted electromagnetic wave consists of a doublet split symmetrically around the incident frequency by an amount equal to the fundamental striation frequency and its higher harmonics. Because of the non-linear nature of the large amplitude, natural striations, 'Bragg doublets' due to several harmonics of the striation frequency have been observed. A knowledge of the scattering angle enables one to determine the wavelength and velocity of the striations. The results for the striation velocity determined from the diffraction measurements are in good agreement with independent measurements made with a photo-multiplier tube. Because of the saw-tooth nature of the electron density profile along the axis of the tube, the diffraction pattern is asymmetric. By measuring the relative intensities of the two doublets, the shape of the electron density profile can be determined.

The diffraction measurements were made at K-band microwave frequencies of 25 Gcs. (λ = 1.2 cms.), with the electric vector of the incident electromagnetic wave polarized perpendicular to the axis of the plasma column. The diffracted signal was detected by using a superheterodyne system in conjunction with an audio frequency wave analyzer. The plasma column was a hot-cathode Argon discharge 50 cms. long and 3.3 cms. in diameter. The neutral gas pressure and discharge current were varied until the discharge operated in a stable, well-defined striation mode. The striations were then controlled and stabilized by using various experimental techniques. Diffraction patterns of up to

the 8th harmonic of the fundamental striation have been measured. It has been observed that the striations are backward waves, with phase velocities directed toward the cathode. Typical values of the striation velocity measured in this experiment varied from 200 meters/sec. at a pressure of 1.9 mms. Hg. to about 480 meters/sec. at 190 μ Hg.

For striations propagating within a finite plasma column the diffraction pattern has been calculated theoretically by using a Born approximation procedure. The intensity of the diffracted electromagnetic wave depends on the striation wavelength, the polarization of the electromagnetic signal and the radial electron density profile within the plasma column. This investigation offers a convenient microwave technique for detecting and analyzing moving striations.

A paper on this subject will be presented at the 1968 Spring URSI meeting to be held in Washington, D.C. on April 9-11, 1968.

Effect of Collision Frequency on the Input Impedance of a Short Cylindrical Antenna in the Vicinity of the Plasma Frequency - L.D. Scott and B. Rama Rao.

Experimental and theoretical investigations have been made to determine the effects of interparticle collisions on the antiresonant impedance characteristics of an electrically short antenna in the vicinity of the plasma frequency. The use of this antenna as a diagnostic probe for measuring effective collision frequency and electron density has been carefully explored using the theories proposed by King[1] et al. and Balmain[2]. The results of this technique are in good agreement with other well accepted diagnostic methods, when suitable corrections are introduced for antenna-transmission line junction effects. This investigation substantiates the recent observations made by Larson[3] which indicate that near the plasma frequency the influence of collision losses on the antenna impedance are similar to that obtained from including electro-

acoustic wave effects. Measurements were made at frequencies from 300 to 600 MHz in a hot-cathode Helium discharge at neutral gas pressures ranging from 35 to 300 μ of Hg. The antenna was a cylindrical copper rod 3.5 cms. long and 4 mm. in diameter.

For estimating electroacoustic mode effects the electron temperature was measured using a Langmuir probe. In a collision dominated plasma like the one used in this investigation the electron temperature effects calculated from Balmain's[2] theory were found to be quite small. It was also determined experimentally by varying the d.c. bias applied to the antenna that the ion sheath contributes negligibly to the antenna impedance. Hence, under these experimental conditions it is justifiable to use a simple, cold plasma model in the analysis of antenna characteristics as suggested by King[1] et al.

Theoretical values of the electron-neutral and electron-ion collision frequencies were calculated by using the collision cross-sections for Helium as measured by Golden and Bandel[4]. The effective collision frequency was then related to the complex dissipation factor used in Langevin's equation for defining the plasma conductivity as suggested by Molmud[5]. The measured values of collision frequencies agree within a factor of less than two in this investigation. This degree of agreement is considered quite good, if one considers possible impurities in the gas, errors in determining electron temperature and neutral gas pressure, and inhomogeneities in the plasma column.

References

1 R.W.P. King, C.W. Harrison, Jr. and D.H. Denton (1961), J. Res. Nat. Bur. Stand., Sec. D, Vol. 65, No. 4, pp. 371-384.

2 K.G.Balmain (April 1965), Radio Science, Vol. 69D, No. 4, pp. 559-566.

3 R.W. Larson (September 1966), Radiation Lab. Tech. Report 7000-25-T, University of Michigan, Ann Arbor, pp. 117-122.

4 D.E. Golden and H.W. Bandel (1965), Physical Review, Vol. 138, No. 1A, pp. A14-A21.

5 P. Molmud (1959), Physical Review, Vol. 114, No. 1, pp. 29-32.

Plasma Profile Investigations Using a Microwave Cavity Technique - B. Rama Rao.

A theoretical analysis has been completed to determine the exact eigen frequencies of cylindrical microwave cavity loaded with an inhomogeneous plasma column. Computer calculations are now underway to determine the effect of a varying parabolic electron density profile on the resonant frequencies of the TM_{oml} and TM_{nmo} type modes excited in the cavity. The wave equations inside the cavity have been solved by a series expansion technique. Depending on the convergence of the series, a sufficient number of terms are evaluated in the computer in order to keep the truncation error within reasonable bounds. When the electron density profile in the plasma column has an axial or azimuthal dependence, certain r.f. modes inside the cavity can become hybrid.

This investigation will determine the effect of inhomogeneous electron density profiles on the accuracy of plasma diagnostics using the microwave cavity method.

Experimental Investigations on r.f. Breakdown Effects in Antennas - B. Rama Rao and L.D. Scott.

Non-linear harmonic and ion-acoustic wave generation during r.f. breakdown in antennas is being investigated. Experiments are being conducted both with and without external d.c. magnetic fields applied to the antennas. Of particular interest is the breakdown at electron-cyclotron resonance. The theory proposed by Lax, Allis and Brown predicts breakdown at very low r.f. effective fields.

This investigation may have some implications on breakdown commonly encountered at high altitudes by antennas mounted on missiles and rockets.

Theoretical and Experimental Studies of Plasma-Coated Antennas - C.Y. Ting and B. Rama Rao.

This investigation has been completed. A paper on this topic has appeared in the

I.E.E.E. Transactions on Antennas and Propagation, March 1968, Vol. AP-16, No. 2, pp. 246-255.

Theoretical Studies on the Circular Loop Antenna in a Plasma Environment - M. Bharathi.

The problem of radiation from a circular loop antenna immersed in a homogeneous isotropic unbounded warm plasma for the case of constant current distribution around the loop is under investigation.

Plasma Diagnostics with Transmission Lines and Cavities - W.A. Saxton and Y.S. Yeh.

A paper entitled "A Modified Theory for Cavity Perturbation Measurement of Plasma Electron Density" has been completed. A second paper on the transmission line in plasma is in preparation.

Theoretical Studies on an Antenna Immersed in a Plasma - A.D. Wunsch.

A dipole antenna of finite radius and length, immersed in a warm, homogeneous and isotropic plasma, has been considered as a boundary value problem. This research has been carried out because it has been suggested by Whale (J.G.R., Vol. 68, pp. 415-422) that the finite temperature of the ionosphere has a direct bearing on the impedance of an antenna carried into the ionosphere by a rocket or satellite. This analysis has essentially been completed and is described in an article which has been accepted for publication by Radio Science. The article provides a number of curves which show the current distribution, impedance, and far field radiation pattern of a plasma immersed antenna.

A tubular antenna has also been considered and expressions have been derived from which the current on the inside and outside surfaces of the tube can be determined

once the total current is known. For the comparatively thin antennas considered in this analysis, it has been found that most of the total current lies on the outside surface of the tube. Thus, the results obtained for the tubular antenna would probably apply to a solid one as well.

The staff now supported in part by this grant includes Professor B. Rama Rao and Dr. C.Y. Ting as well as three part-time students, A.D. Wunsch, L.D. Scott and M. Bharathi.

[redacted]

Submitted by,

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